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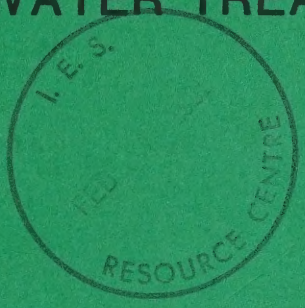
CHLORINATION AND TRIHALOMETHANE FORMATION AT WATER TREATMENT PLANTS



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PRECHLORINATION AND TRIHALOMETHANE FORMATION AT WATER TREATMENT PLANTS

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ABSTRACT

The levels of trihalomethanes (THM) produced at three Metro Toronto water plants were studied, both with and without prechlorination. With prechlorination, average total THM ranged from 10.1 to 14.9 µg/L, well within the maximum acceptable concentration of 350 µg/L defined in the Guidelines for Canadian Drinking Water Quality. Without prechlorination, THM production appeared to be lower on average but organisms of sanitary significance were found regularly to reach the final disinfection stage and plankton counts increased in the finished water; problems with plant operation also developed. The omission of the prechlorination stage should only be considered where properly designed chlorine contact facilities are available, ensuring adequate retention times during final disinfection.

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PRECHLORINATION AND TRIHALOMETHANE FORMATION AT WATER TREATMENT PLANTS

It has been suggested that the trihalomethanes (chloroform, carbon tetrachloride, trichloroethylene, dichlorobromomethane, dibromochloromethane) present in drinking water are generated during the pre-chlorination stage (1,2). Pre-chlorination is employed for several reasons by water plants utilizing surface water supplies, and can achieve such effects as controlling biological growth in the settling basins and the filters, increasing the efficiency of coagulation and lengthening the contact time between the water and chlorine, thereby increasing the disinfection efficiency.

In the light of current concerns regarding the potential health problems associated with trihalomethanes (THM) (3,4) it was of interest to determine, on a plant scale, the effect of removing the pre-chlorination stage from the treatment process, both with respect to the microbiological quality of the produced water and its THM content.

STUDY SITES

Three Metropolitan Toronto water plants were selected for the study. The R.C. Harris (RH) and R.L. Clark (RC) water plants are both conventional full treatment plants, employing pre-chlorination followed by coagulation, settling, filtration and post-chlorination; the former has a capacity of some 11.44 m^3/s and the latter 5.2 m^3/s. The Toronto Island (TI) plant is a direct filtration plant (coagulation followed by filtration) where pre- and post-chlorination are routinely used, with a capacity of 3.12 m^3/s; this plant is normally only brought into operation during the summer months, when the water consumption in the Metro Toronto area increases. All three plants utilize Lake Ontario as a raw water source, but the water quality at each of the intakes is not necessarily the same, because of their location relative to the Toronto harbour and various pollution sources within the general area.

Prior to 1971, pre-chlorination was not practised at any of the plants, but was subsequently introduced following some deterioration in raw water quality. Chlorine at all plants is applied at a level based on the free ammonia content of the raw water, usually at a dose of 1.5 to 3.0 mg/L; the free residual thus produced is normally in the range of 0.3 to 0.5 mg/L. In the final chlorination stage, the chlorine level is adjusted to give a total residual of approximately 1 mg/L and the water is held for thirty minutes to one hour. Immediately prior to distribution, ammonia is added to produce a combined residual, usually in excess of 0.5 mg/L.

In this study, the period during which pre-chlorination was not in effect was limited to between May 29th and July 31st, 1979, inclusive. Towards the end of July, notification was received from the operating staff that pre-chlorination would be reinstituted on August 1st, 1979.

SAMPLING AND ANALYSIS

The study was divided into three phases; an initial phase from mid-April to May 28th, 1979 when the plants were pre-chlorinating; a second phase from May 29th to July 31st, 1979, when pre-chlorination was not carried out and a third phase, from August 1st to mid-September, 1979 when normal plant operation was again reinstated. The TI plant did not begin operating until May 16th and was then followed through until September 18th when it was again placed out of regular service.

Trihalomethanes Collection of water samples for THM analysis was carried out approximately twice per week. Samples of raw and finished waters were taken in bottles containing sodium thiosulphate according to the prescribed method (5) and were analyzed by the direct aqueous injection (DAI) method (6), for total trihalomethanes (THM) and chloroform (C). Samples of finished water were also taken in bottles without sodium thiosulphate; upon analysis, usually about two weeks after collection, these samples yielded a measure of the

total potential trihalomethane (TPTHM) levels in the finished water, ie. that level of THM which is formed after the water has remained in contact with the finished water chlorine residual for an extended period. The amount of THM in distributed water might approach this level, depending upon the residence time of the water and other modifying factors in the distribution system.

Bacteriological Samples for bacteriological analysis were taken at the same time as those for THM, in sterile bottles containing sodium thiosulphate, and were analyzed for the presence of coliform and other pollution indicator bacteria by the presence/absence (P/A) procedure (7). Additionally, the bacteriological records of the water plants themselves were used, where samples of finished water were analyzed for total plate count at 35° C, fecal and total coliforms by membrane filtration (MF) six times per day using standard methods, whilst raw, settled and filtered water were analyzed at least three times per day. These records also provided measurements of chlorine residual, temperature and total chlorine dosage on all samples taken for bacteriological analysis.

RESULTS AND DISCUSSION

Although all three plants derived their raw water from Lake Ontario, the quality of the water was different for each plant. Water quality during this study was assessed by total plate count at 35° C, which would tend to increase with the nutrient level and temperature of the water. As can be seen in Figures 1 a), 1 b) and 1 c), the total plate count of water entering the plant was generally lower at the RH plant, than at either the TI or RC plants, which tended to have similar counts.

Figures 2 a), 2 b) and 2 c), show that the total chlorine dose applied was consistently highest at the TI plant, slightly lower at the RC plant (average dose applied, 2.9 mg/L and 2.4 mg/L respectively) and lowest at the RH plant (average 1.3 mg/L).

Chlorine levels in the finished water without pre-chlorination, did not appear to differ from those when pre-chlorination was practised. Final total chlorine residuals always tended to be higher at the TI plant, somewhat lower at the RC plant with the RH plant showing the lowest final chlorine residuals. These residuals are shown in Figures 3 a), 3 b) and 3 c), and averaged 0.87 mg/L at the TI plant, 0.61 mg/L at RC and 0.53 mg/L at the RH plant.

Since the amount of THM formed in the water would be dependent, in part, upon both the chlorine dosage applied and the quality of the raw water, THM levels at the three plants would be expected to differ; highest levels would be expected where the quality is lowest and the chlorine dosage consequently highest. Comparison of THM production between the three plants, and its relation to the type of treatment applied, was therefore not possible.

As expected, C, THM and TPTHM levels at the RC and TI plants were somewhat higher throughout the study period, as shown in Figures 4 a), 4 b) and 4 c). The average levels of C, THM and TPTHM are shown in Table 1. For the RH plant the average C level with pre-chlorination was 5 µg/L and without pre-chlorination was 3 µg/L; THM averaged 10.1 µg/L and 6.6 µg/L and TPTHM 12.8 µg/L and 13.4 µg/L respectively. Similar results were obtained at the RC plant; C levels were slightly higher at 6.7 µg/L with pre-chlorination and 3.8 µg/L without; corresponding levels for THM were 14.9 µg/L and 8.6 µg/L and for TPTHM 19.5 µg/L and 13.5 µg/L. Data collection at the TI plant over its period of operation yielded an average C level of 7 µg/L, THM 14.1 µg/L and TPTHM 13.8 µg/L, all during the non-pre-chlorination period.

None of the raw waters showed measurable levels of THM, except one sample at the RC plant taken on September 12th, 1979, which contained 50 µg/L THM containing 30 µg/L C. The product water in this case contained lower levels of THM than the raw samples; the reason for this was not determined, but may have been due to an improper sampling procedure.

It was originally felt that the two phases of normal operation would establish baseline data for THM production during pre-chlorination, with the phase 2 data showing production levels during the non-pre-chlorination mode. However, conditions in the raw water were changing as the study progressed, making direct comparison between the three phases difficult, at all three plants. The temperature of the water increased from mid-April to mid-September as shown in Figures 5 a), 5 b) and 5 c). At the RH plant, the average temperature during the first phase of the study was 5.5° C, rising to 7.6° C during the second phase, with the maximum individual temperature of 18.8° C occurring during the third phase, when the average temperature was 11.8° C. The equivalent figures for the RC plant were an average temperature of 5.8° C in phase 1, increasing to 8.5° C in the phase of non-pre-chlorination and 9.8° C in the final phase, when a maximum temperature of 16.6° C was recorded. The TI plant showed similar measurements with 6.5° C, 7.9° C and 10.2° C (maximum 16.4° C). Raw water quality, as measured by the total bacterial count parameter also tended to deteriorate as the study progressed (Figures 1 a), 1 b) and 1 c)) and did so markedly in the third phase on or about August 23rd, 1979.

TABLE I

AVERAGE TRIHALOMETHANE CONCENTRATION
AT THREE METROPOLITAN TORONTO WATER TREATMENT PLANTS

Plant	Trihalomethane	Concentration µg/L	
		Pre-chlorination	
		+	-
R.C. Harris	Chloroform	5	3
	Total	10.1	6.6
	Total Potential	12.8	13.4
R.L. Clark	Chloroform	6.7	3.8
	Total	14.9	8.6
	Total Potential	19.5	13.5
Toronto Island	Chloroform	5*	7
	Total	13*	14.1
	Total Potential	17*	13.8

* Result of one sample only

At all three plants, one-way analysis of variance of the temperature and total bacterial count data (indicative of conditions in the raw water upon which the level of THM production might depend), demonstrated that these parameters did not remain sufficiently stable from phase to phase to allow direct statistical comparison between the three phases.

The production of THM would tend to increase with temperature (8) and with deterioration in quality of the raw water. Therefore, an increase in THM levels would be expected at all three plants as the study progressed from phase 1 through phase 3; an increasing trend in the levels has been observed previously to occur from May through August and September (9). However, during phase 2 (when no pre-chlorination was used) the levels of THM production actually appeared to be lower on average, even though deteriorating quality and increasing temperatures in the raw water should probably have resulted in an increase in those levels; in the absence of the changes in the raw water the reduction in the THM levels might well have been more pronounced.

Although there was little discernible change in the final product water quality as measured bacteriologically at the plant, changes were evident in the intermediate stages of treatment. Thus, as shown in Figures 6 a), 6 b) and 6 c), the total count in the filtered water was higher during the phase where pre-chlorination was not carried out (phase 2); this was true of all three plants, but was most marked at the RC plant. Similarly, P/A analysis showed that indicator bacteria such as coliforms, fecal coliforms and fluorescent Pseudomonas species were reaching the final chlorination stage of treatment in phase 2 . This is supported by the total coliform counts carried out on the filtered water and shown in Figures 7 a), 7 b) and 7 c). At the RC plant an average of 71 per 100 ml was isolated when pre-chlorination was terminated, with 3 per 100 ml and 5.4 per 100 ml being the equivalent levels at the RH and TI plants respectively. Virtually no coliforms were isolated at any of the plants in the filtered water subjected to pre-chlorination during the first phase of the study, although they could be detected

during the period of highly deteriorated raw water quality experienced towards the end of phase 3.

Since indicator organisms including fecal coliforms and Pseudomonas species were able to reach the final disinfection stage in the absence of pre-chlorination, it also might have been possible for pathogenic organisms to survive up to this stage. This would imply that very stringent control must exist on the final chlorination stage, because the safety factor of an additional barrier to pathogenic organisms in the form of a long contact time between the water and a substantial chlorine residual, has been removed; this long contact would effect considerable inactivation of microorganisms. This would be even more critical during periods of highly deteriorated raw water conditions, when indicator organisms could be detected after the filters, even when pre-chlorination was being carried out. Finished water quality was maintained at all three plants throughout the study period, although it has been recommended (10) that the long term microbiological effects of this type of treatment modification be evaluated.

The plankton concentration in the finished water also increased during the shut-down of pre-chlorination although this was controlled at TI and RC by the use of alum addition (11). As the study progressed, in the absence of pre-chlorination, slime growths became established on the filters and other operational problems arose. Operation of the plants was considered to be no longer possible without pre-chlorination.

CONCLUSIONS

The levels of THM produced at the Metro plants studied, are well below the maximum acceptable concentration of 350 µg/L defined in the Guidelines for Canadian Drinking Water Quality (12). Without pre-chlorination, problems in plant operation were perceived to develop, and organisms of sanitary significance were found regularly to reach the final disinfection stage; the safety factor for disinfection would therefore probably be decreased. The omission of the pre-chlorination stage of water treatment should only be considered where properly designed chlorine contact facilities are available, ensuring adequate retention times during final disinfection.

Although THM production appeared to be lower on average in the absence of pre-chlorination, it would not seem advisable to use this method to obtain a reduction in these levels at these three Metropolitan Toronto water plants and possibly compromise the microbiological quality of the product water, especially in view of the initially low THM levels.

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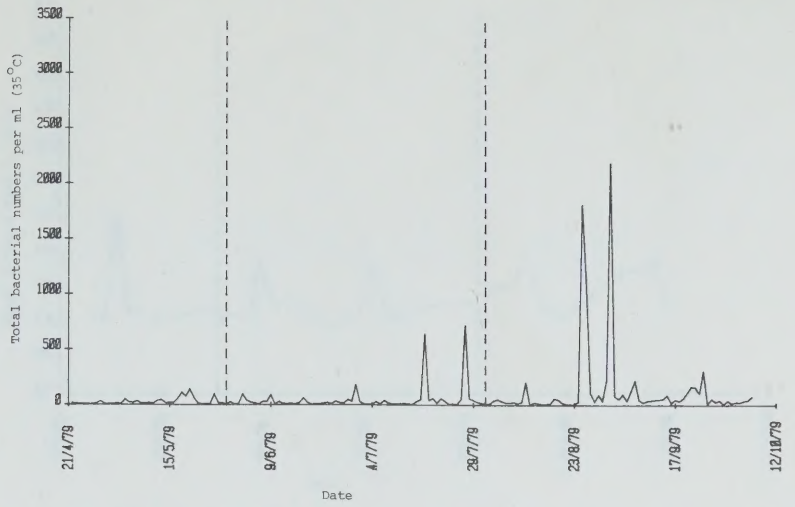


Figure 1 a R.C. Harris WP

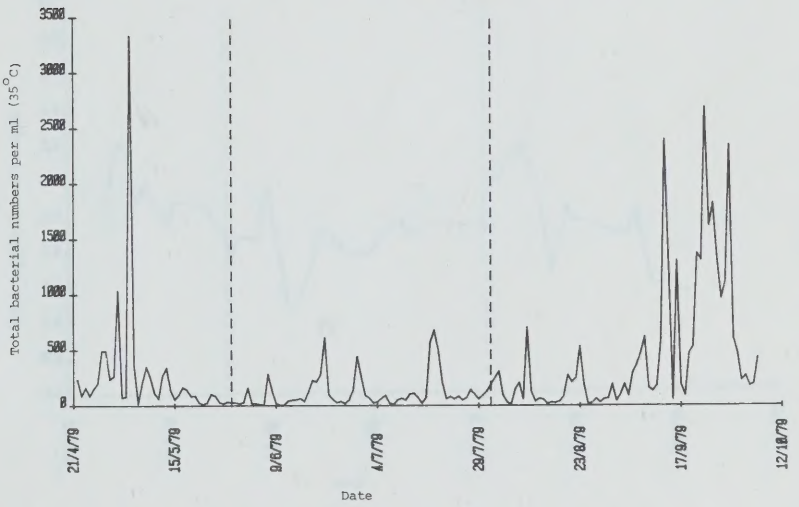


Figure 1 b R.L. Clark WP

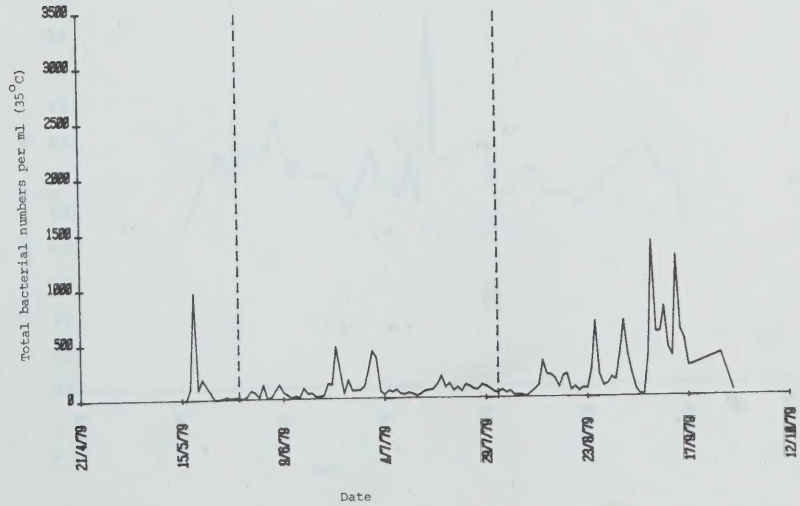


Figure 1 c Toronto Island WP

FIGURE 1a TOTAL BACTERIAL COUNT IN RAW WATER AT THE R.C. HARRIS WP

FIGURE 1b TOTAL BACTERIAL COUNT IN RAW WATER AT THE R.L. CLARK WP

FIGURE 1c TOTAL BACTERIAL COUNT IN RAW WATER AT THE ISLAND WP

Prechlorination was not applied during the period between the vertical broken lines (May 29th to July 31st inclusive).

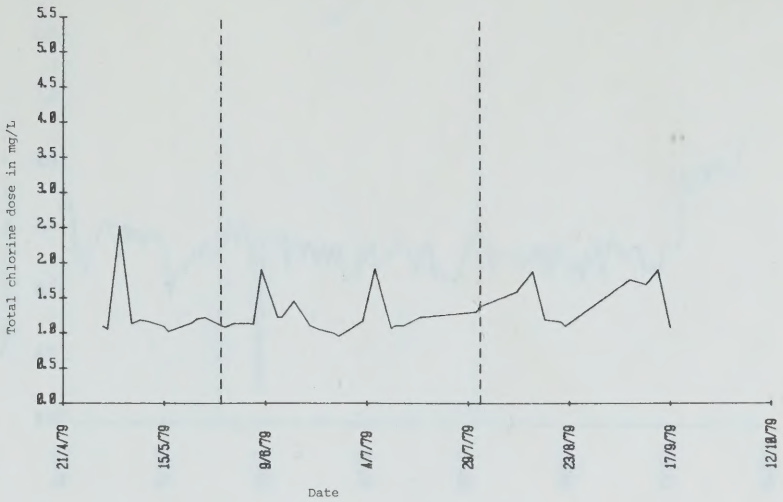


Figure 2 a R.C. Harris WP

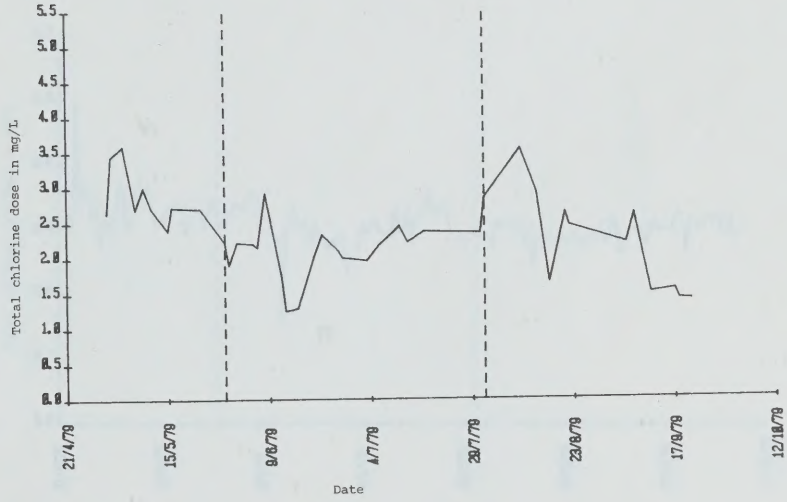


Figure 2 b R.L. Clark WP

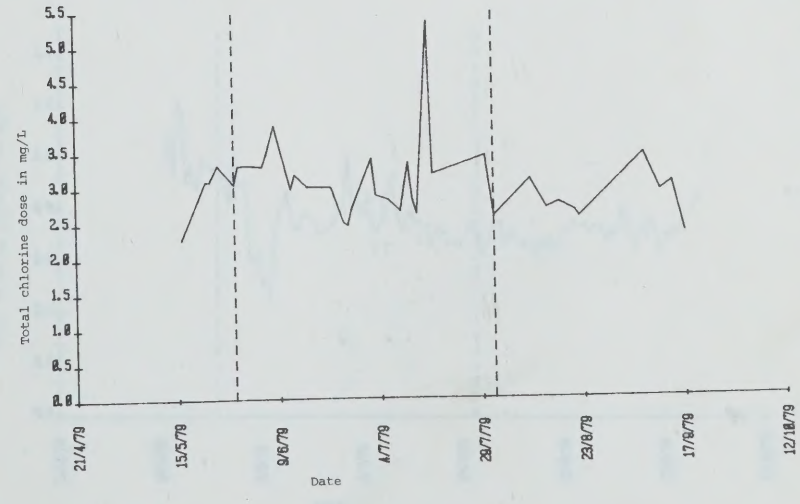


Figure 2 c Toronto Island WP

FIGURE 2a TOTAL CHLORINE DOSE APPLIED TO THE WATER AT THE R.C. HARRIS WP

FIGURE 2b TOTAL CHLORINE DOSE APPLIED TO THE WATER AT THE R.L. CLARK WP

FIGURE 2c TOTAL CHLORINE DOSE APPLIED TO THE WATER AT THE ISLAND WP

Prechlorination was not applied during the period between the vertical broken lines (May 29th to July 31st inclusive) Dose plotted only for those dates where TTHM determinations were made.

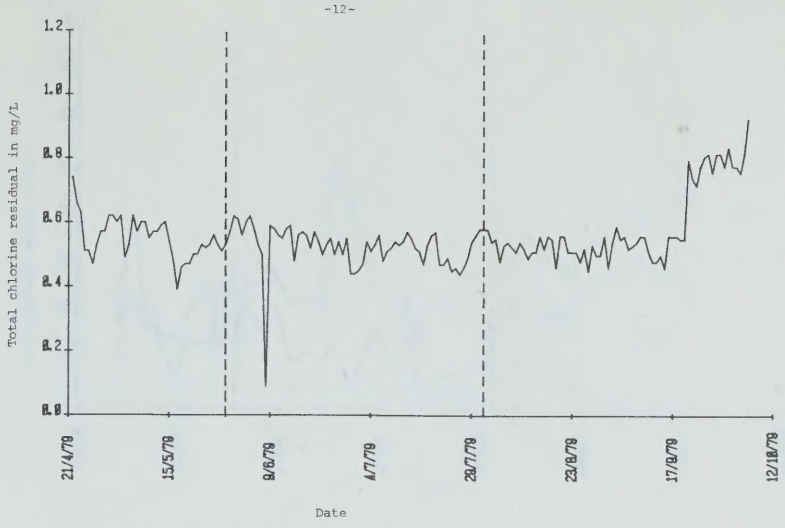


Figure 3 a R.C. Harris WP

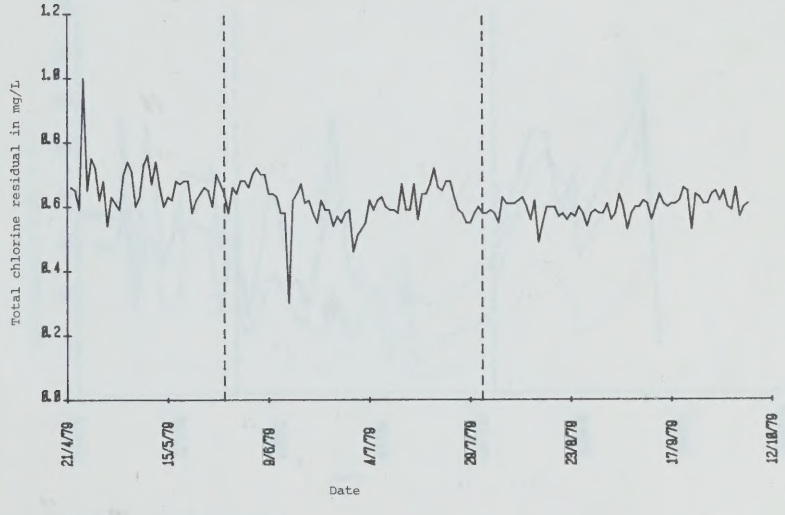


Figure 3 b R.L. Clark WP

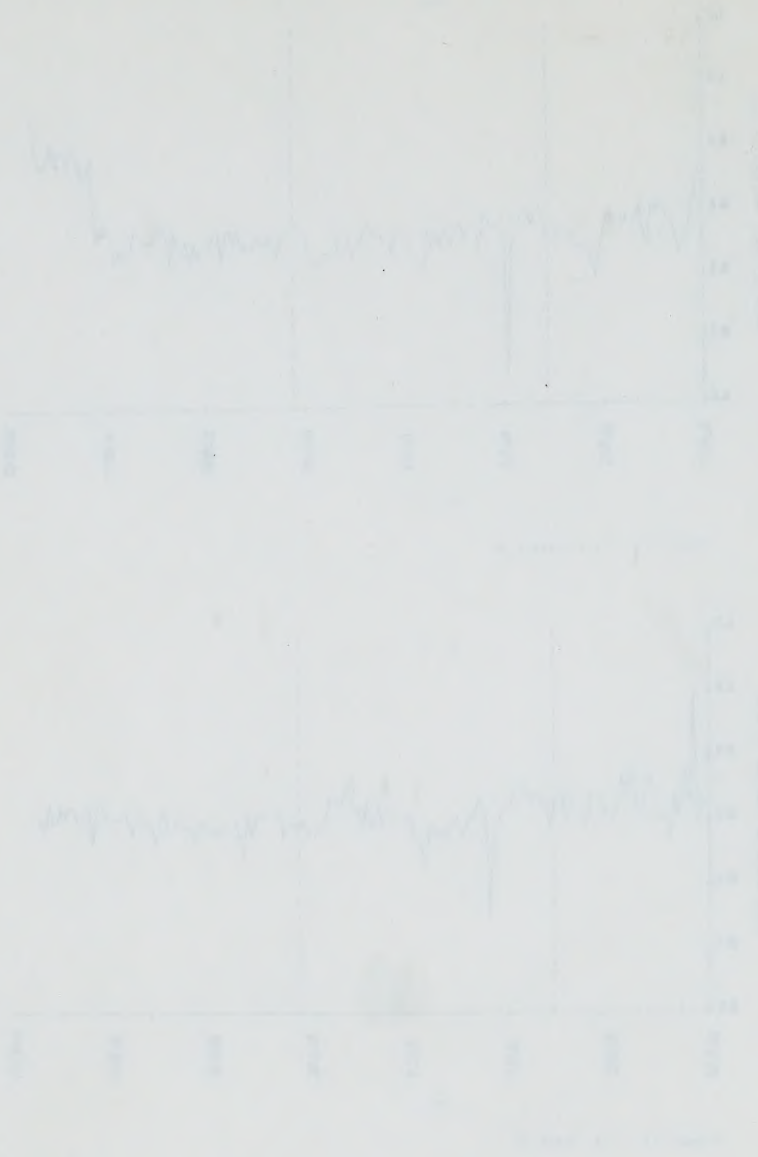
Figure 3 c Toronto Island WP

FIGURE 3a TOTAL CHLORINE RESIDUAL IN THE FINISHED WATER AT THE R.C. HARRIS WP

FIGURE 3b TOTAL CHLORINE RESIDUAL IN THE FINISHED WATER AT THE R.L. CLARK WP

FIGURE 3c TOTAL CHLORINE RESIDUAL IN THE FINISHED WATER AT THE ISLAND WP

Prechlorination was not applied during the period between the vertical broken lines (May 29th to July 31st inclusive)



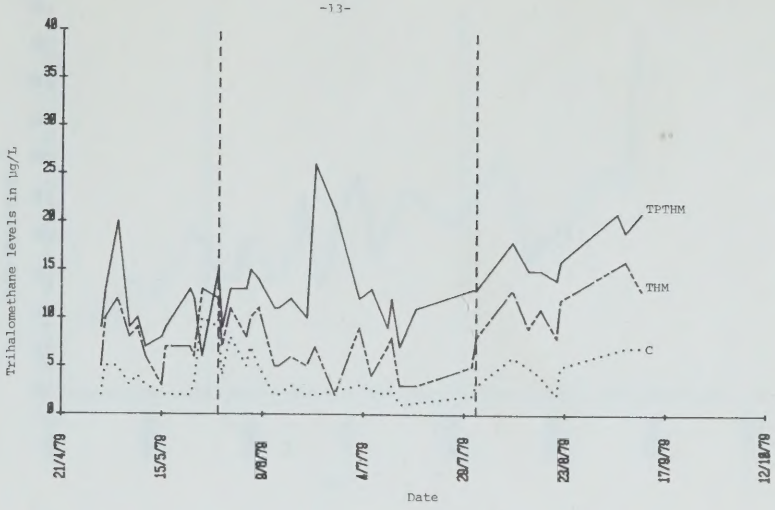


Figure 4 a R.C. Harris WP

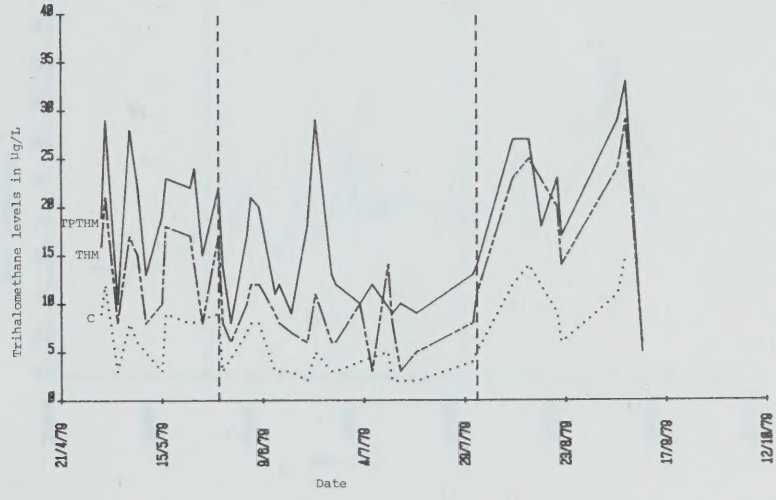


Figure 4 b R.L. Clark WP

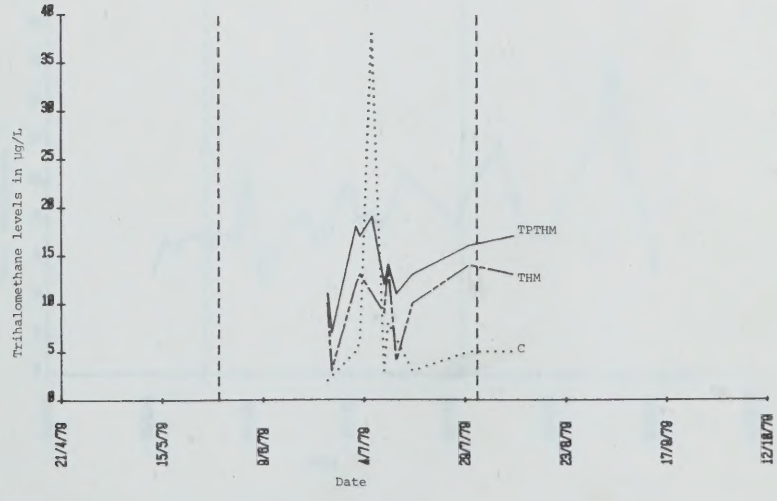


Figure 4 c Toronto Island WP

FIGURE 4a TRIHALOMETHANE LEVELS IN FINISHED WATER FROM THE R.C. HARRIS WP

FIGURE 4b TRIHALOMETHANE LEVELS IN FINISHED WATER FROM THE R.L. CLARK WP

FIGURE 4c TRIHALOMETHANE LEVELS IN FINISHED WATER FROM THE ISLAND WP

Prechlorination was not applied during the period between the vertical broken lines (May 29th to July 31st inclusive)

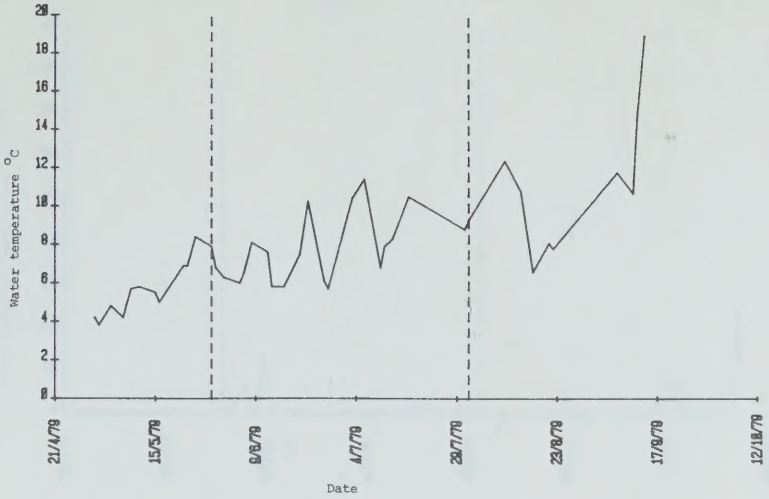


Figure 5 a R.C. Harris WP

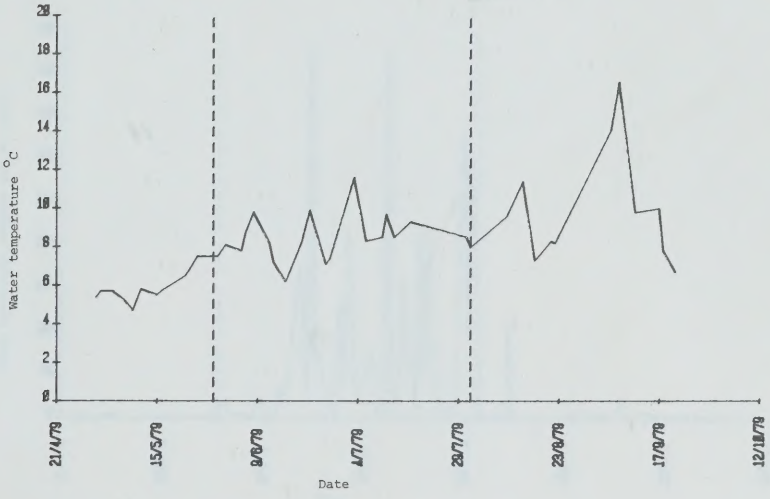


Figure 5 b R.L. Clark WP

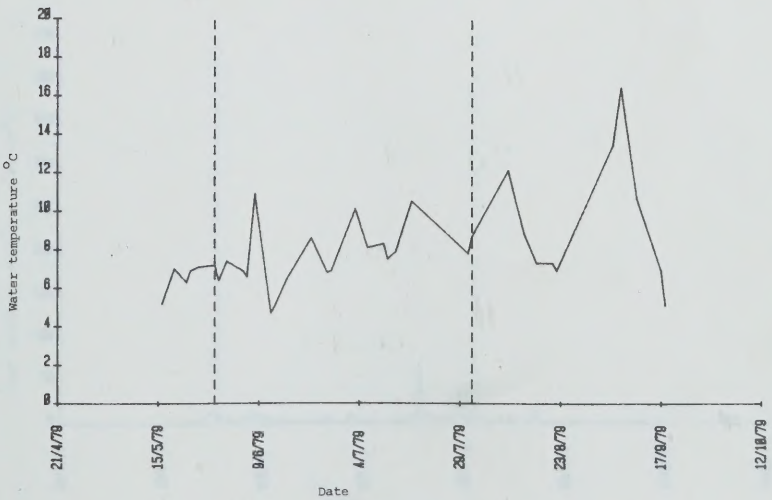


Figure 5 c Toronto Island WP

FIGURE 5a WATER TEMPERATURE IN DEGREES CENTIGRADE AT THE R.C. HARRIS WP

FIGURE 5b WATER TEMPERATURE IN DEGREES CENTIGRADE AT THE R.L. CLARK WP

FIGURE 5c WATER TEMPERATURE IN DEGREES CENTIGRADE AT THE ISLAND WP

Prechlorination was not applied during the period between the vertical broken lines (May 29th to July 31st inclusive) Temperature plotted for only those dates where THM determinations were made.

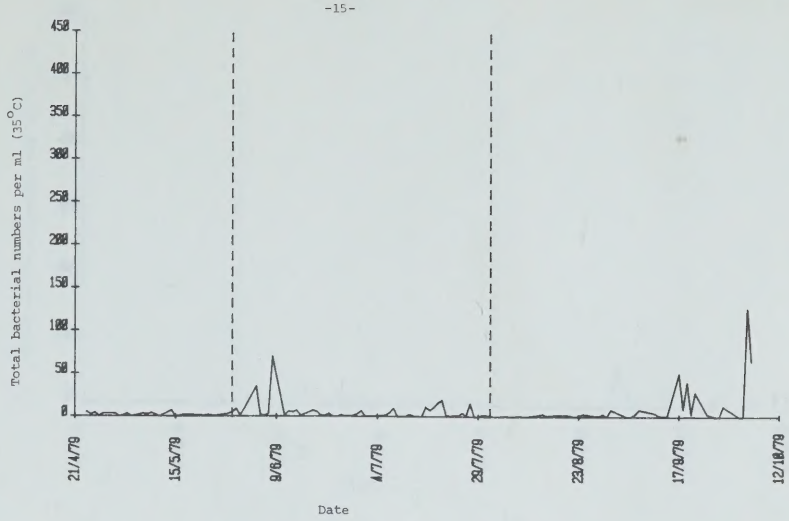


Figure 6 a R.C. Harris WP

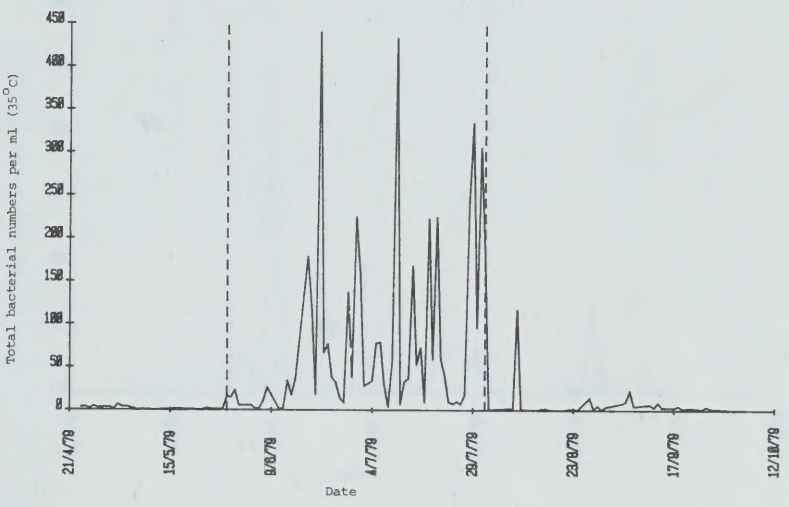


Figure 6 b R.L. Clark WP

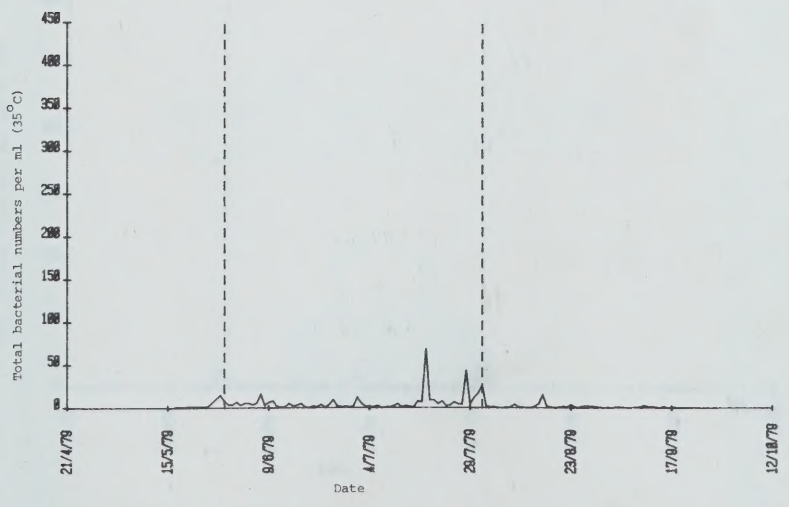


Figure 6 c Toronto Island WP

FIGURE 6a TOTAL BACTERIAL COUNT IN THE FILTERED WATER AT R.C. HARRIS WP

FIGURE 6b TOTAL BACTERIAL COUNT IN THE FILTERED WATER AT R.L. CLARK WP

FIGURE 6c TOTAL BACTERIAL COUNT IN THE FILTERED WATER AT THE ISLAND WP

Prechlorination was not applied during the period between the broken vertical lines (May 29th to July 31st inclusive)

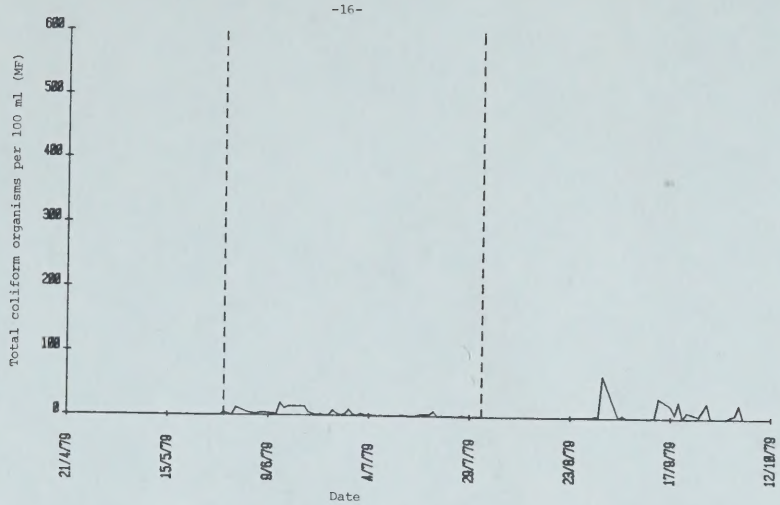


Figure 7 a R.C. Harris WP

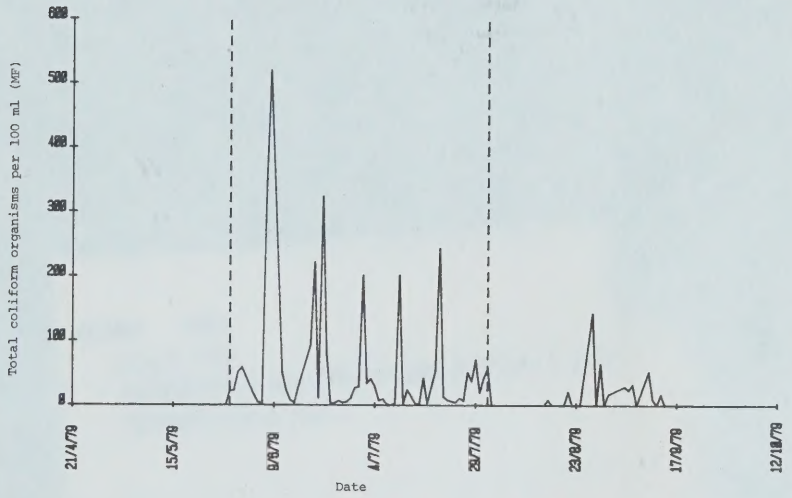


Figure 7 b R.L. Clark WP

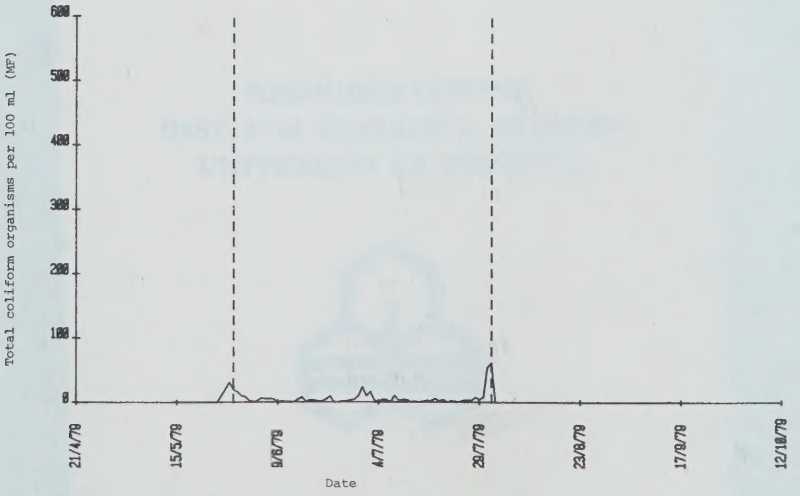


Figure 7 c Toronto Island WP

FIGURE 7a TOTAL COLIFORM COUNT IN THE FILTERED WATER AT THE R.C. HARRIS WP

FIGURE 7b TOTAL COLIFORM COUNT IN THE FILTERED WATER AT THE R.L. CLARK WP

FIGURE 7c TOTAL COLIFORM COUNT IN THE FILTERED WATER AT THE ISLAND WP

Prechlorination was not applied during the period between the broken vertical lines (May 29th to July 31st inclusive)

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PRECHLORINATION AND TRIHALOMETHANE FORMATION AT WATER
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